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ST. CROIX RIVER WATER QUALITY DURING THE YEARS 1965-81

IWD-AR-WQB-83-50

INLAND WATERS DIRECTORATE
ATLANTIC REGION
WATER QUALITY BRANCH
DARTMOUTH, NOVA SCOTIA

ST. CROIX RIVER WATER QUALITY DURING THE YEARS 1965 TO 1981

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INLAND WATERS DIRECTORATE

ENVIRONMENT CANADA

GEOFFREY D. HOWELL

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Atlantic Region

Moncton, New Brunswick

October 24, 1983

LETTER OF TRANSMITTAL

Water Quality Branch
Inland Waters Directorate
Environment Canada
P. O. Box 861
Moncton, N. B., E1C 8N6
October 21, 1983

Chairman, Canadian Section
IJC Pollution Advisory Board
St. Croix River

Gentlemen:

Re: Historical Water Quality Report
St. Croix River - 1965-1981

This report outlines the changes in Water Quality of the St. Croix River at Milltown, N. B. over the period 1965-1981.

The purpose of the report is to have recorded the History of the Water Quality as it relates to changes both in chemical processes at Mill located at Woodland, Me. and method of treatment of the Mill effluent.

Yours sincerely,

D. H. Cullen, Chief
Water Quality Branch

ABSTRACT

During the 1965-1966 period, the dominant major ion in the Saint Croix River was sulphate. However, this changed dramatically in 1966 when the Georgia-Pacific Pulp Mill shifted from the sulphite to the Kraft process. This resulted in a shift in ion dominance from sulphate to sodium and chloride. From the years 1966 to 1981 the overall major ion chemistry remained relatively constant. However, alterations to the pulping process did elicit some specific responses in water chemistry and the relationships between water quality parameters. During the period (1967-1972) when untreated Kraft effluent was discharged directly into the river, both the chemical composition and the discharge rate of the effluent were highly variable. This is reflected by the poor water quality-water quantity relationships. Although this variability was reduced with the adoption of primary effluent treatment in 1972, the most noticeable improvement corresponded to the adoption of the secondary treatment facility in 1977-1978. During the 1978-1981 period, there were good relationships between specific conductance and mean daily discharge as well as specific conductance and the major ions. In addition to regulating discharge rate and effluent composition, secondary treatment greatly improved the summer oxygen regime. Prior to 1978 summer oxygen minima were characteristically below 3.0 mg/L. However, secondary treatment, by lowering the river oxygen demand, improved the oxygen concentrations to levels near to the 5.0 mg/L water quality objective for the Saint Croix River.

RESUME

Durant la période de 1965-1966, le sulfate fut l'ion majeur dominant de la Rivière Sainte-Croix. Cependant, une modification tragique fut observée en 1966 lors du changement du sulfite au processus de Kraft utilisé à la papeterie "Georgia-Pacific Pulp Mill". Ceci resulte à un changement au niveau de la dominance ionique du sulfate au sodium et au chlore. Depuis lors de cette observation en 1966, jusqu'en 1981, une relation relativement constante persiste en rapport avec l'ensemble globale de la chimie des ions majeurs. De plus, les modifications du processus de la papeterie provoqua des réponses spécifiques en ce qui concerne la chimie de l'eau et la relation entre les paramètres de la qualité des eaux. Pendant les années 1967-1972 quand l'effluent non-traite de Kraft fut deversé directement dans la rivière, la composition chimique ainsi que la vitesse d'écoulement furent très variables. Ce phénomène fut réfleté par une pauvre relation entre la quantité et la qualité de l'eau. Même si l'instabilité fut réduite avec l'adoption d'un premier traitement de l'éffluent en 1972, l'amélioration la pluz évidente fut observée suite à l'adoption d'un deuxième traitement en 1977-1978. Durant la période de 1978-1981, il existe des bonnes relations entre la conductance spécifique et la moyenne quotidienne du debit ainsi que la conductance spécifique et les ions majeurs. En plus du reglage de la vitesse d'écoulement et la composition de l'éffluent, le traitement sécondaire améliora grandement le regime estivale en oxygene. Avant l'été de 1978, la valeur minima de l'oxygène fut charactéristiquement sous la valeur de 3,0 mg/L. Etant un

abaissement de la demande d'oxygène dans la rivière, le deuxième traitement améliora la teneur en oxygène a un niveau de 5,0 mg/L qui fut l'objectif de la qualité des eaux pour la Rivière Sainte-Croix.

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1. INTRODUCTION

In 1966, the IJC established the Advisory Board on Pollution Control of the Saint Croix River. This board was given the responsibility for water quality monitoring and co-ordination of water quality planning activities in the Saint Croix River Basin. To assist the board in fulfilling the mandate, the Water Quality Branch of Environment Canada has conducted systematic water quality sampling and co-operated in the development of water quality objectives with particular reference to the passage of the Atlantic salmon (*salmo salar*). In addition, other agencies such as the USGS and the Maine Department of Environmental Protection also regularly monitor the Saint Croix River for selected water quality parameters.

The Saint Croix River forms the international boundary between Canada and the United States and has a reach of approximately 124 km. Of the total length it is only the lower 14 km which is of immediate water quality concern (Figure 1). This represents the stretch between Woodland, Maine and Milltown, New Brunswick. The reason for this is a major industrial discharge at Woodland and to a lesser extent, municipal discharges and sewage overflows from the towns of Woodland and Baileyville. At Woodland, the Georgia-Pacific Corporation operates a Kraft Pulp Mill which produces fully bleached Kraft pulp and discharges the treated effluent into the Saint Croix River.

As a consequence of the combined sampling efforts of the USGS and

the Water Quality Branch, there is an historical water quality data base for the Milltown station (00NB01AR0001) dating from July 23, 1965 to November 27, 1981. It is the intention of this report to use this data set to elucidate long term water quality trends and to relate water quality changes to alterations at the Georgia-Pacific Pulp Mill.

2. DATA PRESENTATION

The water quality data set has been subdivided into four groups, corresponding to major changes at the Georgia-Pacific mill. The first group incorporates data from 1965 and 1966, when the plant produced pulp using the magnesium based sulphite method. This process was replaced during 1966 following the construction of the Kraft Mill and the bleach plant in 1965. The second data set runs from the fall of 1966 to the spring of 1972 and includes the period when Kraft Mill effluent was discharged directly into the Saint Croix River without primary treatment. In the spring of 1971, primary effluent treatment, including the clarifier went into operation. In addition, a minimum lime system for colour removal was in operation during 1969, 1970 and 1971. The data set for this period included data up to the spring of 1972 in order to ensure sufficient time for adoption of the primary treatment facility into the regular operation of the production system.

The third period of data commences in the spring of 1972 and runs to December 1977. This period is characterized by Kraft effluent which undergoes primary treatment prior to discharge. The treatment facility was upgraded to a secondary extended aeration stabilization system during the spring of 1977. As was the case with the previous data set, a short time lag is included in the data set to ensure continuous operation of the new system. The final group includes all data during the period when the Kraft Mill effluent was processed through the secondary treatment facility and discharged into the Saint Croix River.

This data set begins in January of 1978 and runs to the end of November of 1981.

As a consequence of the long time period of sample collection, the analytical techniques employed have undoubtedly changed. A description of Water Quality Branch techniques is given in the February 1970 edition of the NAQUADAT dictionary. Those data collected and analysed by the USGS are also likely to be subject to problems associated with changes in analytical techniques. A description of USGS analytical methods is given in U.S. Geological Survey Techniques of Water Resources Investigations report series.

Due to the large amount of data involved, (both the number of observations and parameters), it is not feasible to present raw data tables. Thus Table 1 presents the medians, ranges and sample sizes for selected parameters for each of the four data sets. Medians were employed rather than means, as their more robust nature makes them less sensitive to occasional outliers.

The following discussion is subdivided into four sections, corresponding to each of the four data sets. Thus data from each time frame will be analysed separately and an attempt will be made to characterize the water quality of the period and present water quality relationships. These sections will discuss only those water quality parameters which are affected by the Georgia-Pacific Mill and give insight into the processes which control the water quality of the Saint Croix River.

The discussion will be followed by a short summary which will attempt to compare the water quality features during the four time periods and relate any changes to alterations at the Georgia-Pacific Pulp Mill.

3. RESULTS AND DISCUSSION

3.1 1965-1966 Data Set

The period of 1965-1966 only represents twelve months of water quality monitoring at Milltown as is reflected by the small number of observations (n=13). However this was an important period as the pulp was produced by an entirely different process than that employed thereafter.

Specific conductance ranged from 40 uS/cm to 94 uS/cm and had a median value of 53 uS/cm. The 1982/83 report on the St. Croix River monitoring program (Howell & Lockerbie, 1983) has indicated that there is generally a good logarithmic relationship between mean daily river discharge and specific conductance. However it has also been noted that this relationship is valid only when there is a relatively constant production and effluent discharge rate at the Georgia-Pacific Pulp Mill. For the 1965-1966 data set there is a poor relationship (r=0.64) between the logarithmic values of discharge and specific conductance (Table 2). This would indicate that the rate of effluent discharge and/or the ion ratios are highly variable during this period. This is to be expected as it corresponds to the period of Kraft Mill and bleach plant construction and the subsequent preparation for switching from the sulphite process to the Kraft process.

As would be expected the dominant major ion is sulphate which

ranged from 8.0 mg/L to 33.0 mg/L and had a median value of 12.1 mg/L. Although the highest values were found during low flow conditions, as was the case for specific conductance, there was a poor logarithmic relationship with daily mean discharge. This supports the contention that the Mill effluent discharge during this period was somewhat irregular. Specific conductance is often used as an indicator of the total dissolved solids and thus is usually well related to the concentration of specific major ions, particularly those which are dominant. This is the case for sulphate concentration (Figure 2) which is well related to the specific conductance (r=0.904). However, the other major ions (Cl, Na, Mg, Ca, Alk) are only poorly related to specific conductance. In fact these ions exhibit little variation, remaining relatively constant over a large range of specific conductivities (Table 1). The exception to this is sodium which has a maximum concentration of 17 mg/L. However it is probable that this is the result of contamination and exclusion of this value results in a range of sodium concentrations of 1.2 mg/L to 2.5 mg/L. This would suggest that these major ions are near to background levels and are not significantly influenced by the effluent discharge.

3.2 1966-1972 Data Set

This period includes samples collected at Milltown between August 1966 and March of 1972 and consists of approximately 80 observations. This time span encompasses a period where the Kraft pulp process was employed and the effluent was discharged into the river with no treatment.

Specific conductance ranged from 38 uS/cm to 177 uS/cm and had a median value of 67 uS/cm. Although the linear relationship between the logarithmic values of specific conductance and mean daily discharge is poor (Table 2), it is greatly affected by five outliers (Figure 3). One of these outliers is a sample collected on the ascending portion of the discharge hydrograph and thus appears to be a consequence of a lag in chemical response to changing discharge. In fact, a sample collected two days after this on the descending portion of the hydrograph had a much lower specific conductance and fell close to the predicted regression line. The other four outliers occurred during the month of April during the years of 1967 and 1968. These four samples have much higher specific conductivities than would be expected given the river discharge. In addition these samples also exhibit unusual chemical dominance, having high concentrations of calcium and bicarbonate ions. Although the explanation for this phenomenon is not intuitively obvious, it may be the result of an occasional short term alteration in the process of the Georgia-Pacific Pulp Mill. The most likely explanation would be the occasional flushing of the lime kiln which would account for elevated concentrations of both calcium and bicarbonate. Exclusion of these five outliers would greatly improve the relationship increasing the regression coefficient from -0.74 to -0.89. This further emphasizes the contention that river discharge is well related to the ionic constituents only when the effluent discharge rate and the ionic proportions of the effluent remain relatively constant.

The major ion chemistry during this period is dominated by sodium and chloride. This is to be expected as the Kraft process employs predominantly sodium and chloride containing chemicals (EPS MS. Report, 1974). Sodium concentrations ranged from 1.0 mg/L to 35.5 mg/L and had a median value of 5.0 mg/L while the concentration of chloride had a range of 0.5 mg/L to 18.0 mg/L with a median value of 7.5 mg/L.

A good relationship would be expected between specific conductance and the dominant ions (sodium and chloride) however this was not observed (Figures 4 and 5). In fact these figures indicate two separate relationships with conductance for each of the dominant ions. Scrutiny of the individual points which comprise the lower relationship indicates that these values correspond to periods when the ion dominance shifts to calcium and bicarbonate. Further support of this observation is provided by the relationship between specific conductance and calcium concentration (Figure 6), where there also appears to be a double relationship, with the points on the upper curve relating to those on the lower curve of the chloride and sodium figures. Exclusion of the lower points on the curve improves the relationships between specific conductance and chloride (r increases from 0.53 to 0.74) and specific conductance and sodium (r increases from 0.66 to 0.90) considerably.

The other major ions (sulphate, potassium and magnesium) and total alkalinity were only poorly related to the specific conductance.

Although the concentrations of magnesium and potassium were stable, sulphate and total alkalinity showed considerable variation. Sulphate concentrations ranged from 4.2 mg/L to 21.0 mg/L with a median of 7.8 mg/L while the median for total alkalinity was 12.0 mg/L with values ranging from 2.5 mg/L to 42.6 mg/L. This variability is expected as both parameters are affected by the Kraft process. The more variable nature of total alkalinity can be explained by the combined effects of the Kraft process, flushing of the lime kiln and the employment of a colour removal system during 1969-1971.

A parameter of major concern in the St. Croix River is the dissolved oxygen concentration. However, this parameter was not routinely measured until the fall of 1971. Therefore the 1967-1972 period has only 6 measurements of dissolved oxygen with values ranging from 5.9 mg/L in October of 1971 to a high of 11.6 mg/L in November 1971. The median concentration was 10.8 mg/L. These values all exceed the water quality objective of 5.0 mg/L however it must be emphasized that they do not include any summer values when dissolved oxygen is characteristically at a minimum.

3.3 1972-1977 Data Set

This section incorporates data collected at Milltown from April of 1972 up to the end of the 1977 calendar year. This data corresponds to a period of Kraft effluent which undergoes primary treatment (including a clarifier) prior to discharge into the Saint Croix River and includes approximately 52 observations for the major ions and a greatly increased frequency for the physical parameters (~150).

Specific conductance during this period ranged from 29 uS/cm to 210 uS/cm and had a median value of 64 uS/cm. Although there is an inverse relationship between the logarithmic values of specific conductance and mean daily discharge (Table 2), a few outliers result in a low regression coefficient. Of the six obvious outliers (Figure 1), four correspond to periods of rapidly ascending discharge and thus can probably be explained by a lag in chemical response. There is no obvious explanation for the other two outliers, however it is likely that much of variation in the relationship is due to fluctuations in the rate of effluent discharge.

The dominant major ions during this period were sodium and chloride and both of these parameters were well related to the specific conductance (Figures 8 & 9). The regression coefficients for these two relationships were 0.94 and 0.91 respectively. Chloride concentrations ranged from 1.6 to 56. and had a median value of 6.1 mg/L. Sodium had a median concentration of 5.0 mg/L and a range of 1.7 mg/L to 29 mg/L.

In addition to chloride and sodium, total alkalinity and calcium are also well related to specific conductance having regression coefficients of 0.76 and 0.78 respectively (Table 2). The fact that these four major ions are well related to specific conductance, would suggest that the ionic dominance of the effluent discharge during this period remains relatively constant. This may be a consequence of the

primary treatment procedure which by increasing the residence time of the effluent within the system tends to damp any variation in the chemical constituents.

Three major ions (sulphate, magnesium and potassium) are only weakly correlated with specific conductance. This is to be expected for potassium and magnesium as they show little seasonal variation and are not of particular importance in the Kraft pulp process. However, sulphate is used in the pulp process and would therefore be expected to be related to specific conductance. There are two possible explanations for this result. Firstly, sulphate concentrations were determined by a colourimetric method which has since been shown to be inappropriate for analysis of coloured waters (Kerekes et al., 1983). A second possibility is that low oxygen concentrations during the summer months would enable bacterial formation of hydrogen sulphide which in the fall could subsequently be re-oxidized into sulphates. In fact, the seasonal distribution of sulphate concentrations indicates that peak values are generally found during the late autumn. This summer reduction and fall reoxygenation would serve to alter the temporal distribution of sulphate and may account for the poor linear relationship. Although it is possible that these high fall values are merely an artifact of colour interference, since autumnal water colours are not significantly greater than those found during other times of the year, this appears to be unlikely.

This period has a good data record of dissolved oxygen

concentration with values ranging from 1.2 mg/L to 13.0 mg/L. The seasonal distribution of dissolved oxygen follows a regular pattern, with the highest values found during periods of low water temperature in the spring, winter and fall and the lowest values during high water temperatures in the summer (Figures 10, and 11). This seasonal trend is characteristic of coloured waters which generally range from 80 to 100 percent saturated with dissolved oxygen. The exception to this trend is during the summer period when there is a high chemical and biological oxygen demand, resulting in severe reduction of oxygen concentrations and saturations. During every summer during the years 1972-1976 inclusive, minimum oxygen concentrations well below the present 5.0 mg/L water quality objective were observed. In addition values well below the water quality objective of 60 percent saturation were recorded during each summer. The final year of this data set (1977) had a similar oxygen distribution, however the summer minimum oxygen values of 6.1 mg/L or 75% saturation were somewhat higher than those recorded during the previous years. The improvement in oxygen concentrations during the summer of 1977 can be attributed to the implementation of a secondary treatment plant in April of 1977.

3.4 1978-1981 Data Set

This data set consists of approximately 80 observations collected at Milltown between January of 1978 and November of 1981 and represents a period when Kraft effluent underwent secondary waste treatment. The secondary process includes a settling pond to reduce the suspended solid

load followed by an extended aeration stabilization system.

The specific conductance during this period ranged from 33 uS/cm to 150 uS/cm and had a median value of 65 uS/cm. With the exception of one obvious outlier there was a good logarithmic relationship between specific conductance and mean daily discharge (Figure 12). Linear regression on the logarithmic values indicated an improved relationship having a regression coefficient (r) of -0.78 (Table 2). This outlying value appears to be a consequence of a lag in response to a rapidly falling hydrograph. By the following day, the specific conductance had increased from 33 uS/cm up to 108 uS/cm and fell close to the regression line. Removal of the one outlier (Figure 12) increased the regression coefficient to -0.86. This good relationship would indicate that both the effluent discharge rate and chemical composition remained relatively stable during this period. This is probably a consequence of the incorporation of the secondary effluent treatment facility which due to an approximate eleven day retention time tends to both damp temporal chemical changes and regulate the effluent discharge rate.

The relatively constant chemical composition of the effluent discharge is emphasized by the good relationships between the major ions and specific conductance. As would be expected sodium and chloride are closely related to specific conductance with both having regression coefficients of 0.94 (Figures 13 and 14). In addition nearly all the other parameters which are affected by the mill effluent were closely related to specific conductance (Table 2).

Sulphate concentrations ranged from 3.2 mg/L to 15.3 mg/L and had a median value of 6.5 mg/L. Interpretation of sulphate data has recently been shown to be complicated in coloured waters due to interference of the regularly used methyl thymol blue method by organic acids. However as the relationship between sulphate concentrations and total organic carbon concentrations (r=0.17) was poor, there does not appear to be a significant overestimation of sulphate due to colour interference. Thus it can be assumed that the observed relationship (r=0.86) between sulphate concentration and specific conductance is realistic (Figure 15). Two other major ions, magnesium and calcium were also closely related to specific conductance having regression coefficients of 0.92 and 0.81 respectively. Total alkalinity, however, was only poorly related to the conductance having a regression coefficient of 0.62.

In addition to damping temporal chemical fluctuations of the effluent, the secondary treatment facility, by lowering the BOD, has resulted in considerable improvement of the oxygen regime (Figure 16). The summertime oxygen concentrations during this period were generally very near to or above the water quality objective of 5.0 mg/L set for the river, even during periods of very low river discharge such as that recorded on August 23, 1978 (755 cfs; O_2=5.3 mg/L). However, strict control of river discharge rate must be maintained in order to avoid episodal oxygen depletion as was observed for one period during the summer of 1980. On August 28, 1980, an electrical malfunction at the Woodland Mill caused a reduction in the release of water from the Grand

Falls dam. This resulted in a low river discharge rate at Baring, at one point during the day reaching 530 cfs. During this period the Woodland Mill continued to release treated effluent into the river. The undiminished loading of treated mill effluent to the river at low river discharge rates and high water temperatures (23.0^{o}C) resulted in low dissolved oxygen levels at Milltown. Dissolved oxygen concentrations were below the 5.0 mg/L objective for 6 days following the incident, and at one time during the period reached 0.5 mg/L. Hence it is evident that without this control, it will not be possible to ensure a successful run of Atlantic Salmon in the river.

4. SUMMARY

By far the greatest change in water chemistry of the Saint Croix River occurred during 1966 when the Georgia-Pacific Mill switched from a sulphite process to a Kraft process. In 1965 and early 1966 water chemistry at Milltown was characterized by high sulphate concentration and to a lesser extent elevated magnesium values. The shift to the Kraft process and establishment of the bleach plant, had by the summer of 1966 reduced the concentrations of sulphate and magnesium in the river. However, concomitant with this, concentrations of sodium and chloride and to a lesser extent calcium and total alkalinity increased significantly. All of these major ions are employed in the Kraft process. In addition to the shift in major ion composition, the Kraft process appears to be responsible for a significant increase in the specific conductance of the Saint Croix River. Once the Kraft process was initiated there appears to be no alteration in the overall major ion chemistry from the period of 1966 up to 1981. This is indicated by the relatively similar median values of the major ions for the last three data sets presented in Table 1. However, modifications to the Kraft process have led to changes in both the variability of the chemical composition of the Kraft effluent and other water quality parameters.

During the five years from 1966 to 1972 the Kraft effluent was discharged directly into the Saint Croix River with no treatment. This was reflected in the water quality at Milltown which was highly variable for this period and appeared to depend on fluctuations in process at Georgia-Pacific. In most instances, the water quality of this period was

Na^+ and Cl^- dominated, however it would occasionally shift to Ca^{++} and HCO_3^- dominance. This appears to be caused by an occasional flushing of the lime kiln and/or the colour removal system which was operational during 1969 to 1971. This variable chemical nature of the effluent is reflected by both the poor relationship between discharge and specific conductance and specific conductance and the major ions. During the next six years, from 1972 to 1978, the Kraft effluent underwent primary treatment and clarification prior to discharge into the Saint Croix River. Although the rate of effluent discharge was still variable as indicated by the poor discharge and specific conductance relationship (Figure 7), the chemical dominance appears to be somewhat more stable. This is reflected by the much improved linear relationships between sodium and specific conductance (Figure 8) and chloride and specific conductance (Figure 9). This is likely the result of increased residence time of effluent in the primary treatment facility which allows greater mixing of effluents from different phases of the Kraft process. The final data set covers the period of 1978 to 1981 and corresponds to effluent undergoing secondary treatment prior to discharge. This period is characterized by both a relatively constant effluent discharge rate and chemical composition as is indicated by the good relationships between discharge and specific conductance and specific conductance and the major ions respectively (see Table 2). Much of this appears to be the result of the eleven day retention of effluent in the aeration ponds of the secondary treatment facility. This serves to regulate not only the chemical composition of the effluent but also the rate of discharge.

In addition, the secondary waste treatment facility has resulted in a considerable improvement in the summertime oxygen regime of the Saint Croix River. During the six years (1972-1978) of primary effluent treatment summertime oxygen concentrations were characteristically low. In fact the minimum value recorded was 1.2 mg/L, a value far below the water quality objective of 5.0 mg/L. The adoption of the secondary treatment facility, reduced the suspended solid load and the BOD of the effluent and has thus served to improve summer oxygen concentrations considerably. The summertime oxygen concentrations during the 1978-1981 period were generally near to or above the water quality objective and the minimum value recorded was 4.9 mg/L. Not only does the improved oxygen regime have considerable biological importance, such as allowing the passage of Atlantic salmon, but may also have some important chemical implications.

During the period 1972 to 1978, although sulphate loading by the Kraft effluent was significant, there was a surprisingly poor relationship between specific conductance and sulphate concentration. It is suggested that the reason for this poor relationship is that during the low oxygen concentration periods during the summer some of the sulphate may be reduced to sulphide by bacterial activity. During the 1978 to 1981 period, the much improved summer oxygen conditions would not allow development of sulphate reducing bacteria. This may explain the improved relationship between sulphate and specific conductance observed for this period.

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ACKNOWLEDGEMENTS

The authors would like to thank Mr. G. Pierce of the Georgia-Pacific Corporation for providing historical information on the Woodland Pulp Mill. We also greatly appreciate the use of the United States Geological Service data which significantly increased the historical data base. We are thankful to Messrs. R. Bingham and L. Wong for computer and data processing support, and Mrs. L. Boulter for typing the manuscript. The review and criticism of the manuscript by Mr. D. Cullen and Dr. T. Pollock and the support of the entire Water Quality Branch is appreciated.

LIST OF TABLES

TABLE 1 Minimum, maximum, median values and number of observations for selected parameters for each of the four Saint Croix River data sets.

TABLE 2 Linear regression analysis between the logarithmic river discharge and specific conductance and the specific conductance and several selected major ions.

TABLE 1: Minimum, maximum, median values and number of observations for selected parameters for each of the four St. Croix River data sets

Data Set	Statistic	Mean daily disch. CFS	Specific Conduc. uS/cm	Chloride mg/L	Sulphate mg/L	Total Alk. mgCaCO3/L
#1	Minimum	470	40	2.1	8.0	L1.0
1965-1966	Maximum	5000	90	3.5	33.0	8.5
	Median	1135	53	2.7	12.1	5.8
	n	13	12	10	10	11
#2	Minimum	425	34	0.5	4.2	2.5
1966-1972	Maximum	9400	139	18.0	21.6	42.6
	Median	1800	68	7.5	7.8	12.0
	n	80	79	70	70	71
#3	Minimum	809	29	1.6	4.0	4.0
1972-1978	Maximum	19990	210	56.0	12.5	27.0
	Median	2400	64	6.1	6.5	9.5
	n	142	139	45	53	55
#4	Minimum	667	33	1.5	3.2	6.0
1978-1981	Maximum	12996	150	21.0	15.3	25.0
	Median	1700	65	7.1	6.5	14.0
	n	83	81	60	73	54

TABLE 1 (Cont'd)

Data Set	Statistic	Calcium mg/L	Magnesium mg/L	Potassium mg/L	Sodium mg/L
#1	Minimum	3.5	0.7	0.3	1.2
1965-1966	Maximum	6.8	5.4	1.0	17.0
	Median	3.7	2.8	0.4	1.7
	n	11	11	11	11
#2	Minimum	3.0	0.7	0.2	1.0
1966-1972	Maximum	18.9	2.0	1.8	35.5
	Median	5.5	0.9	0.6	11.0
	n	64	15	72	69
#3	Minimum	2.6	0.5	0.3	1.7
1972-1978	Maximum	10.0	3.7	3.5	29.0
	Median	4.2	0.7	0.6	5.0
	n	52	43	45	47
#4	Minimum	3.0	0.2	0.2	1.2
1978-1981	Maximum	6.0	1.0	1.4	22.0
	Median	4.2	0.7	0.6	6.5
	n	53	56	59	76

TABLE 2: Linear regression analysis between the logarithmic river discharge and specific conductance and the specific conductance and several selected major ions

DATA SET #1 (1965-1966)

Log Discharge	= 1.74 log Sp. Cond. + 6.19	r = -0.64 NS
Sulphate	= 0.430 Sp. Cond. - 11.0	r = 0.90 *
Sodium	= 0.005 Sp. Cond. + 1.40	r = 0.27 NS
Chloride	= 0.014 Sp. Cond. + 1.72	r = 0.64 NS
Calcium	= 0.013 Sp. Cond. + 3.27	r = 0.37 NS
Alkalinity	= -0.025 Sp. Cond. + 6.92	r = 0.22 NS
Magnesium	= 0.009 Sp. Cond. + 0.05	r = 0.65 NS

DATA SET #2 (1966-1972)

Log Discharge	= -1.27 log Sp. Cond. + 5.67	r = -0.74 *
Sulphate	= 0.061 Sp. Cond. + 3.98	r = 0.59 *
Sodium	= 0.111 Sp. Cond. - 2.20	r = 0.66 *
Chloride	= 0.082 Sp. Cond. + 0.25	r = 0.53 *
Calcium	= 0.035 Sp. Cond. + 3.19	r = 0.45 *
Alkalinity	= 0.250 Sp. Cond. - 3.35	r = 0.69 *
Magnesium	= -0.005 Sp. Cond. + 1.57	r = -0.22 NS

DATA SET #3

Log Discharge	= -1.26 log Sp. Cond. + 5.68	r = -0.73 *
Sulphate	= 0.023 Sp. Cond. + 5.05	r = 0.32 NS
Sodium	= 0.127 Sp. Cond. + 1.97	r = 0.94 *
Chloride	= 0.149 Sp. Cond. - 2.08	r = 0.91 *
Calcium	= 0.054 Sp. Cond. + 1.21	r = 0.78 *
Alkalinity	= 0.170 Sp. Cond. + 0.32	r = 0.76 *
Magnesium	= 0.004 Sp. Cond. + 0.38	r = 0.35 NS

DATA SET #4

Log Discharge	= -1.40 log Sp. Cond. + 5.90	r = -0.78 *
Sulphate	= 0.074 Sp. Cond. + 1.31	r = 0.86 *
Sodium	= 0.143 Sp. Cond. + 2.59	r = 0.94 *
Chloride	= 0.129 Sp. Cond. - 1.67	r = 0.94 *
Calcium	= 0.024 Sp. Cond. + 2.51	r = 0.81 *
Alkalinity	= 0.109 Sp. Cond. + 5.76	r = 0.62 *
Magnesium	= 0.008 Sp. Cond. + 0.07	r = 0.92 *

* Significant at a = 0.01

NS Not significant at a = 0.01

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3 Linear relationship between mean daily discharge and specific conductance for the 1966-1972 data set.

4 Linear relationship between sodium concentration and specific conductance for the 1966-1972 data set.

5 Linear relationship between chloride concentration and specific conductance for the 1966-1972 data set.

6 Linear relationship between calcium concentration and specific conductance for the 1966-1972 data set.

7 Linear relationship between mean daily discharge and specific conductance for the 1972-1978 data set.

8 Linear relationship between sodium concentration and specific conductance for the 1972-1978 data set.

9 Linear relationship between chloride concentration and

specific conductance for the 1972-1978 data set.

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11 Seasonal variation in dissolved oxygen concentration for the years 1975 to 1976.

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14 Linear relationship between chloride concentration and specific conductance for the 1978-1981 data set.

15 Linear relationship between sulphate concentration and specific conductance for the 1978-1981 data set.

16 Seasonal variation in dissolved oxygen concentration for the years 1979 to 1980.

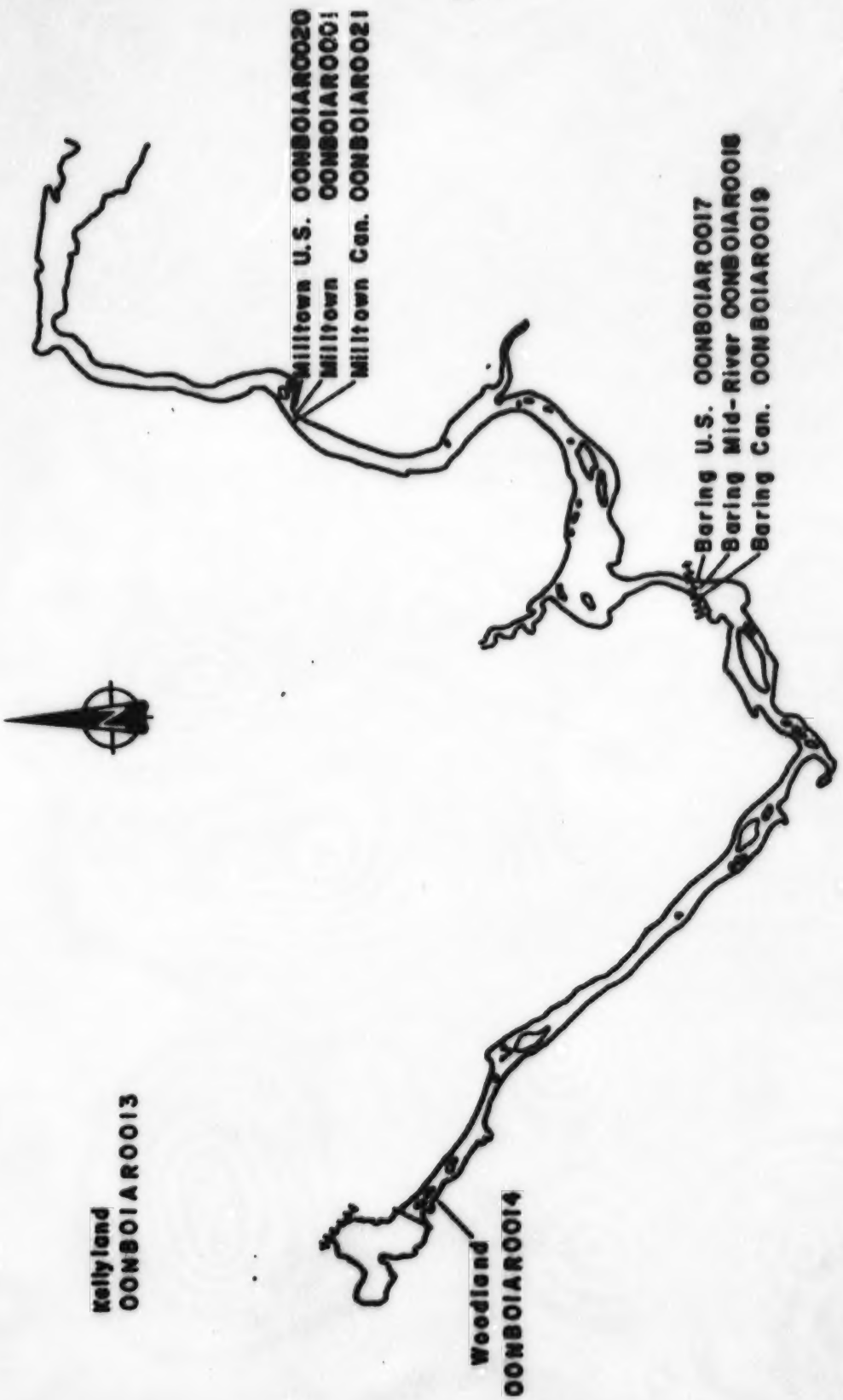


Fig. 1 Map of Study Area

FIGURE 2. (1965-1988 DATA)

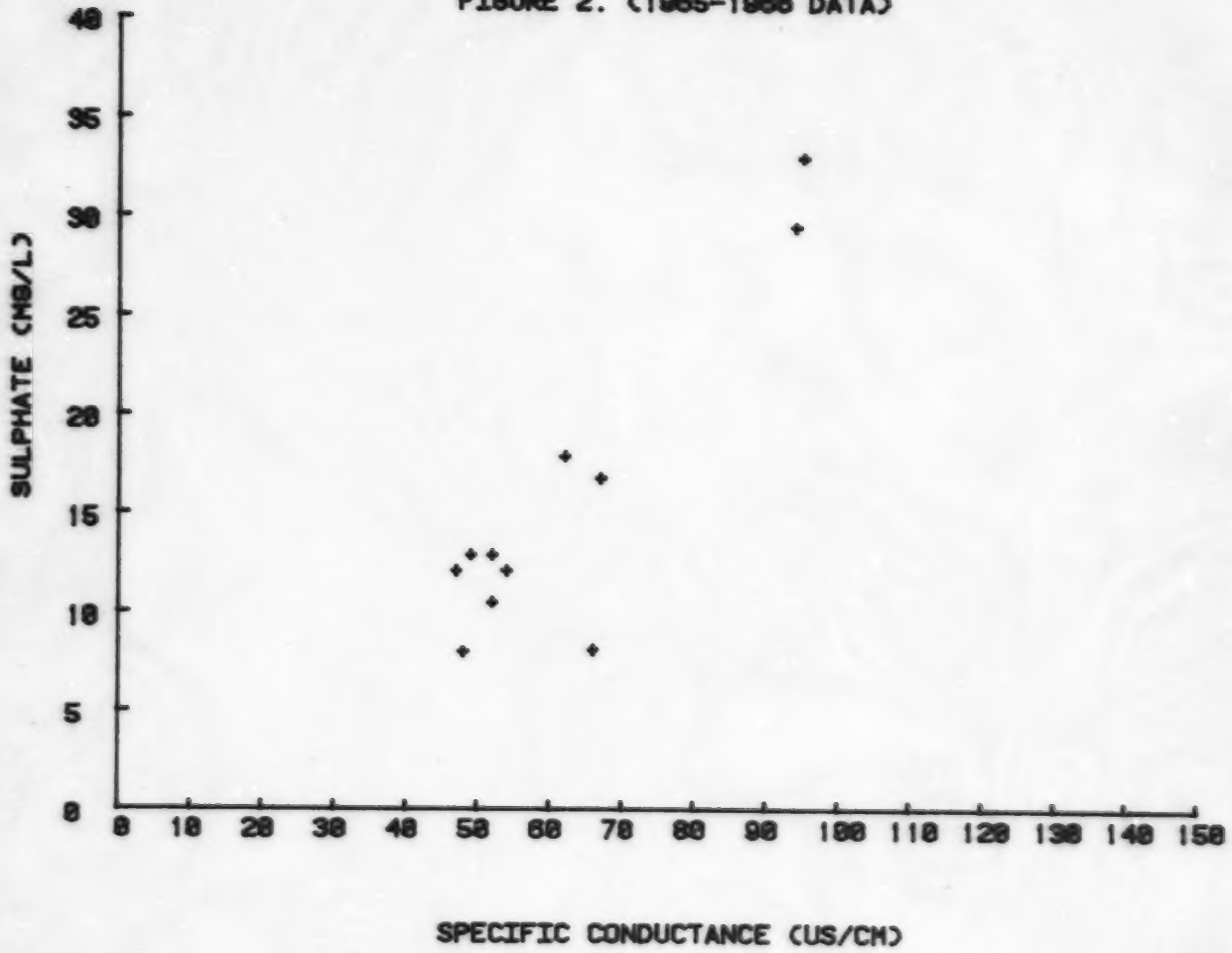
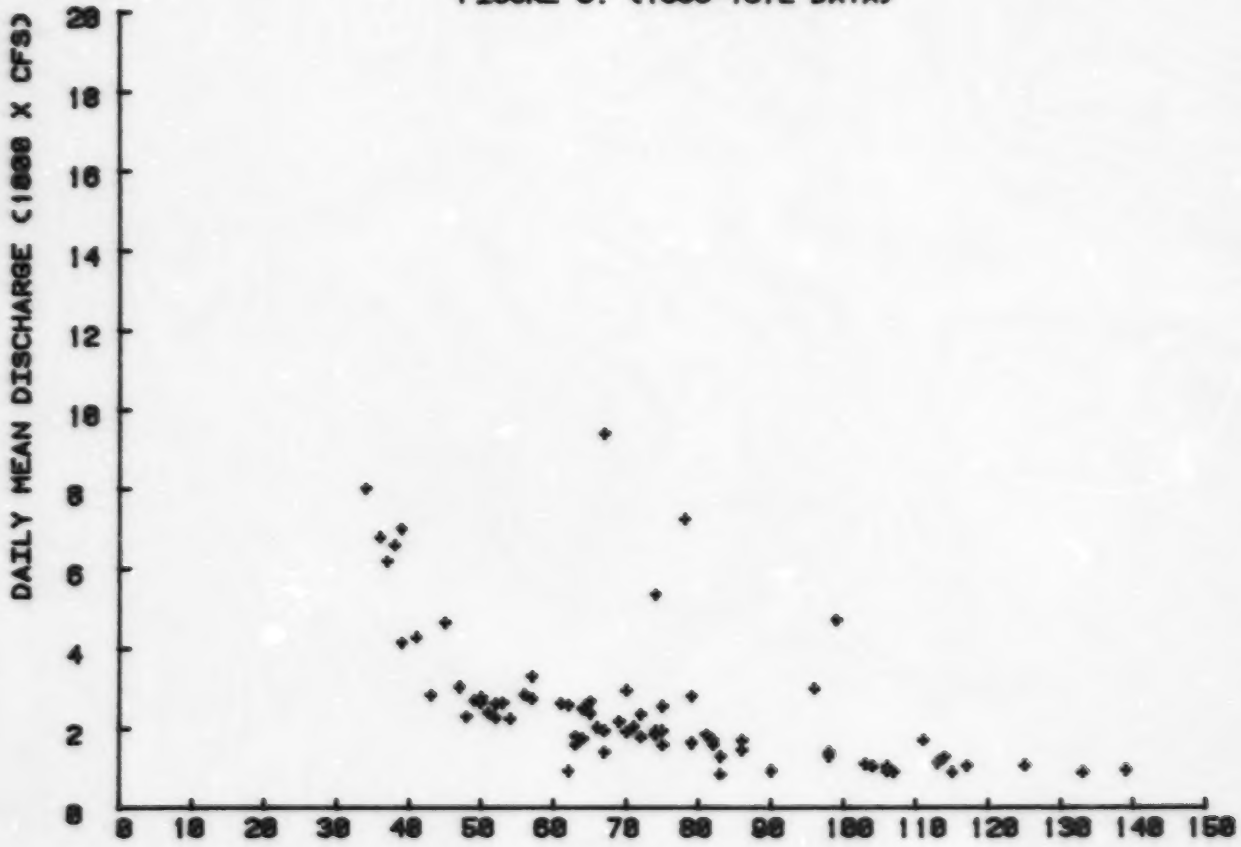


FIGURE 3. (1966-1972 DATA)



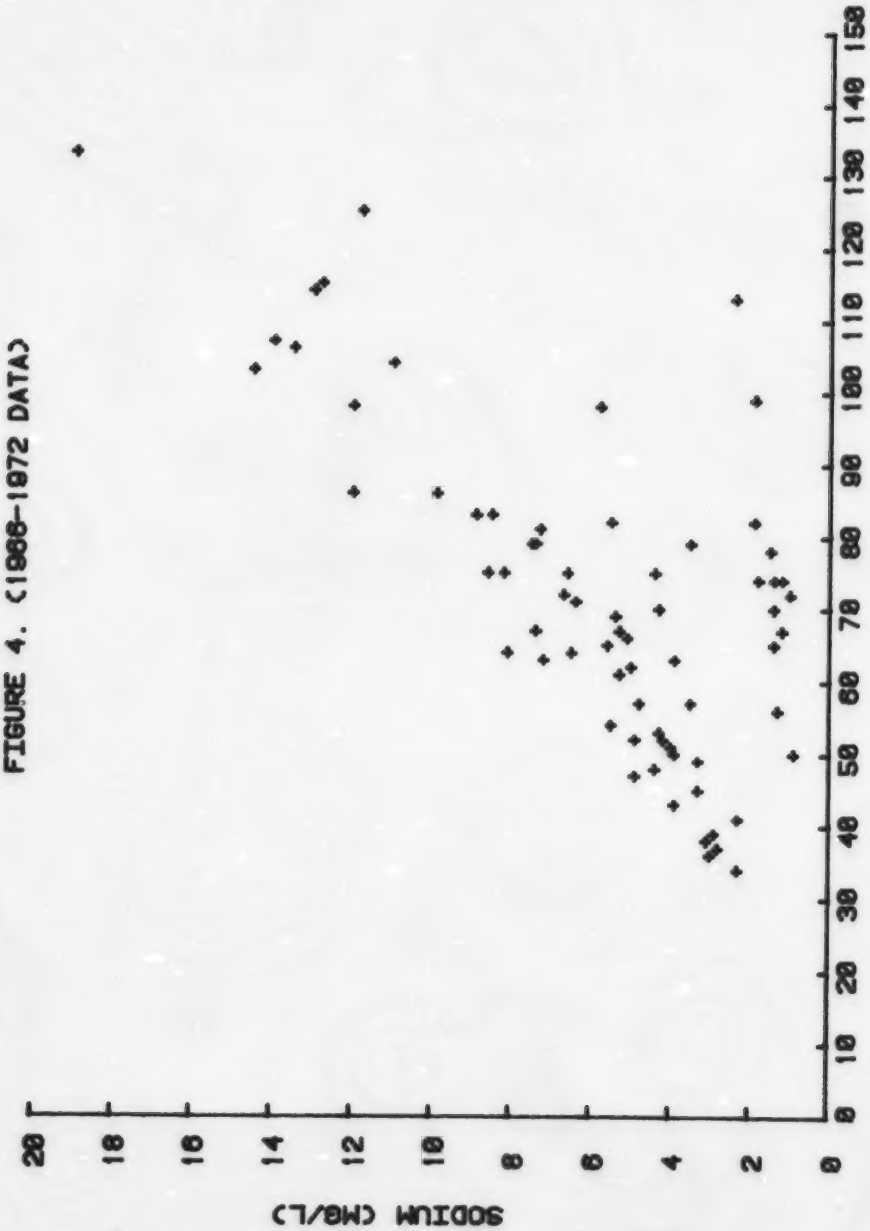
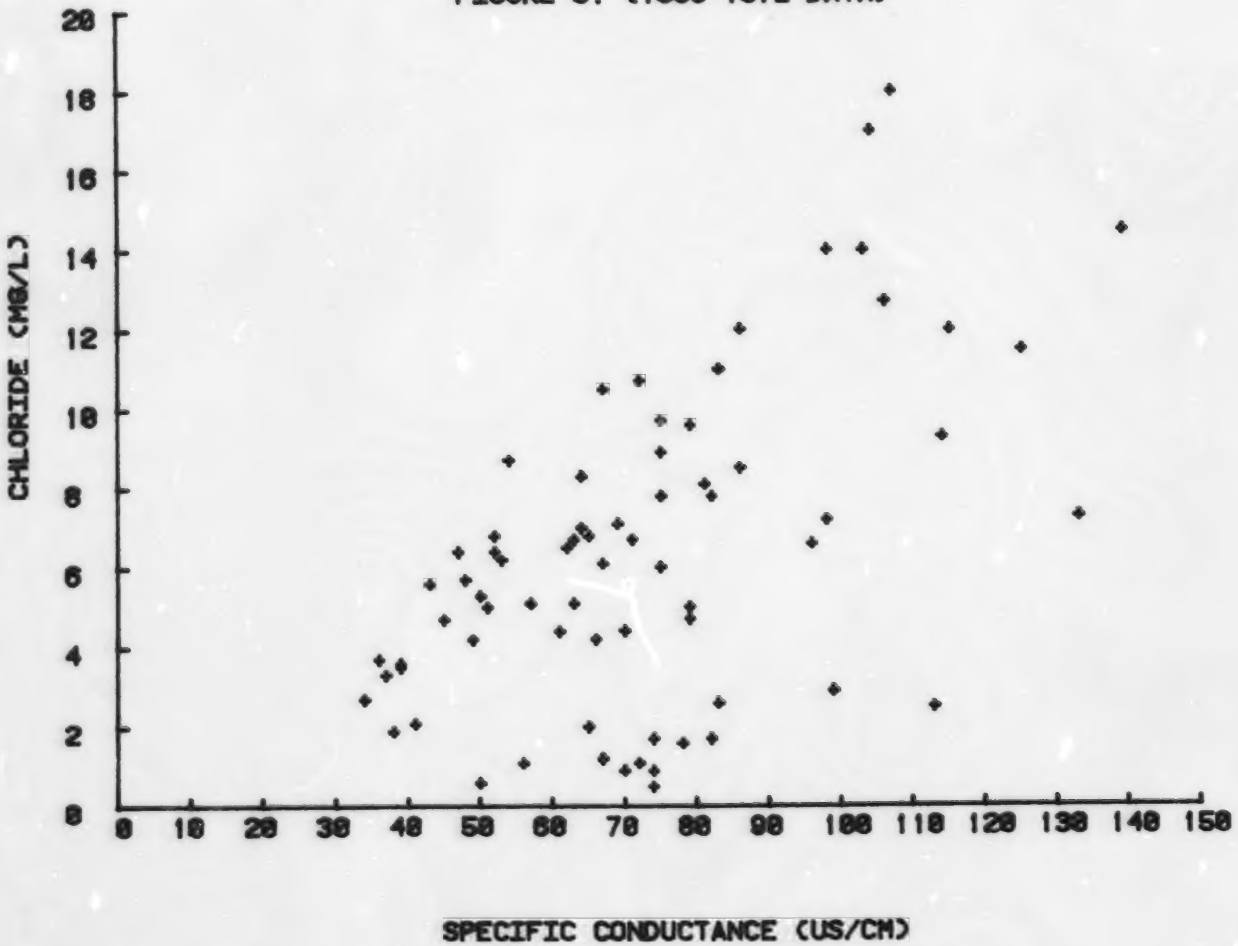


FIGURE 4. (1966-1972 DATA)

FIGURE 5. (1966-1972 DATA)



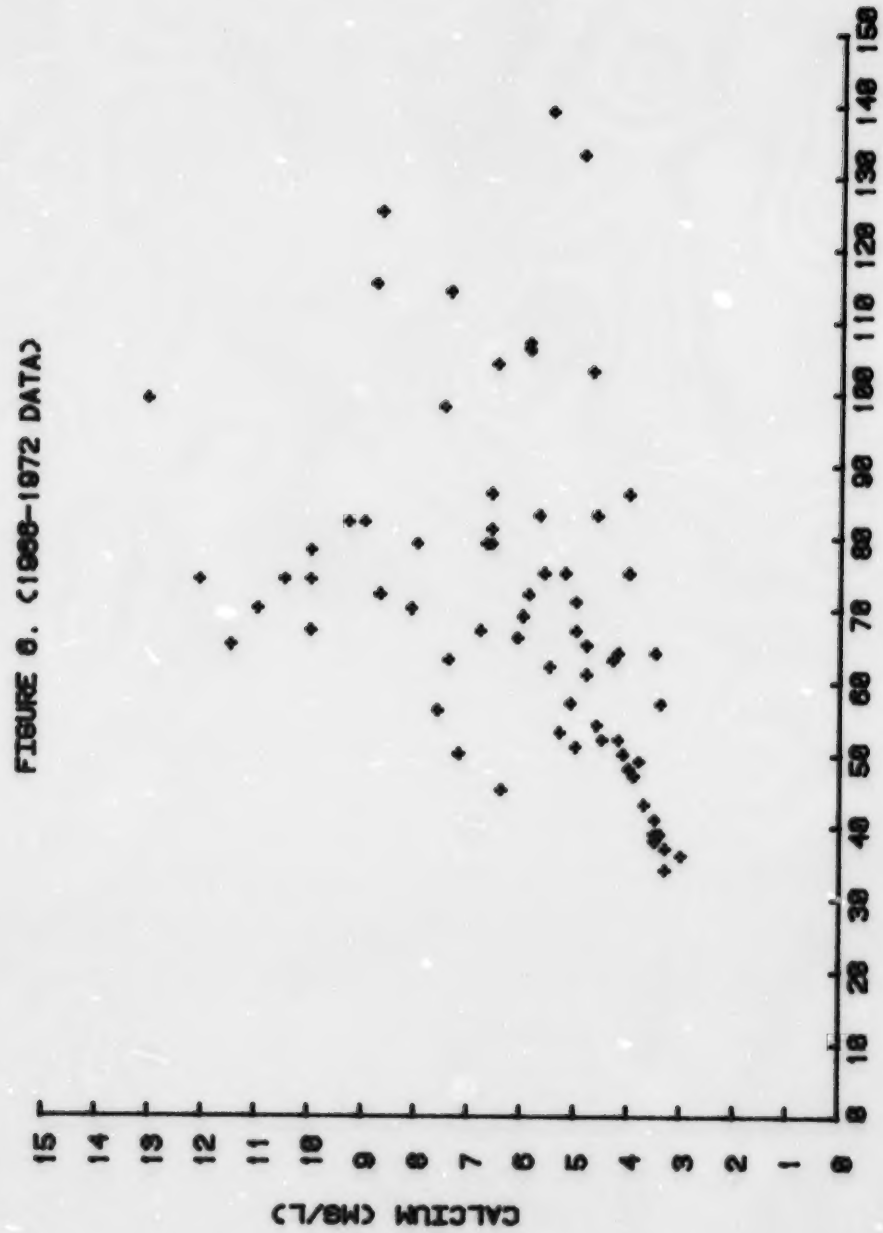
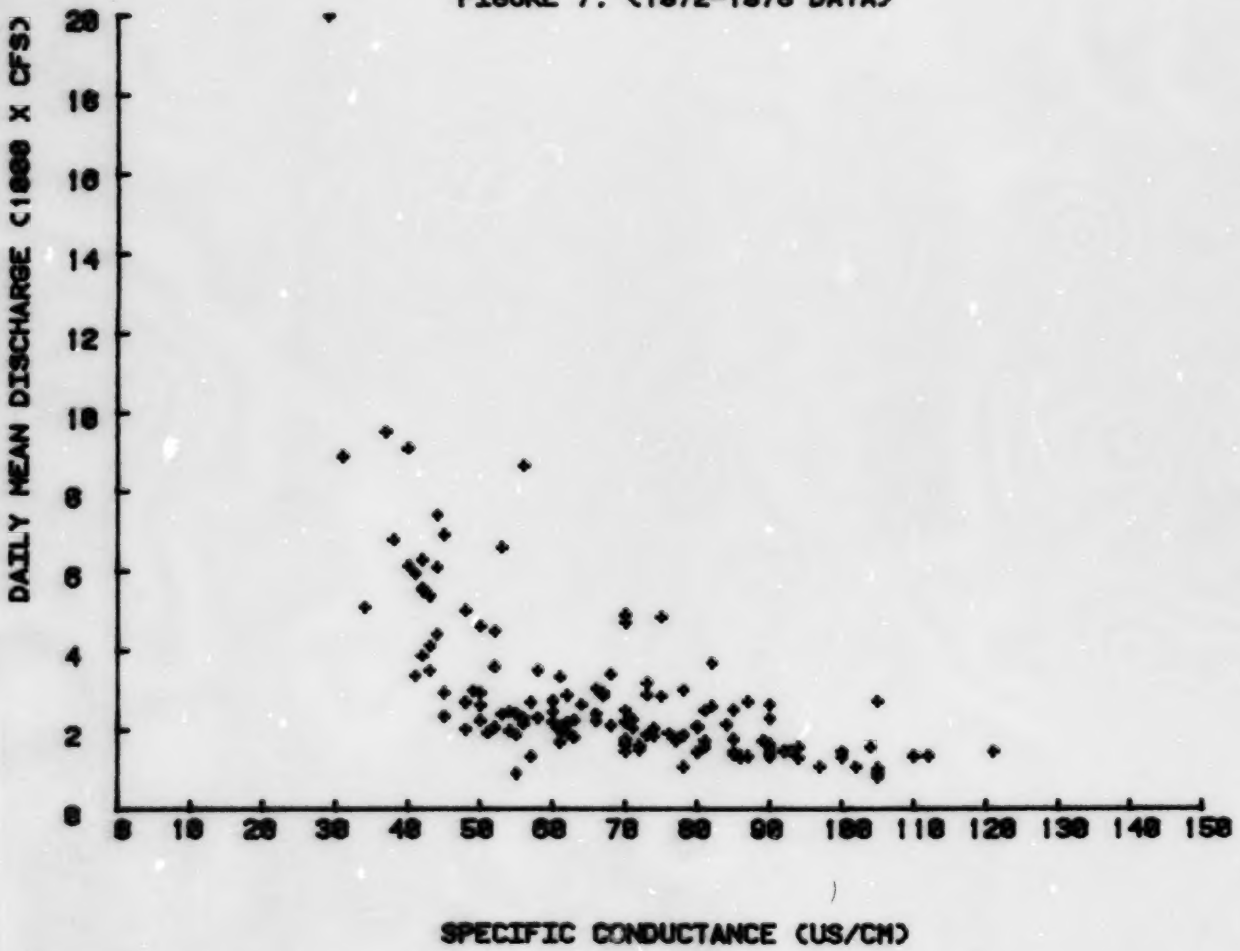


FIGURE 8. (1968-1972 DATA)

FIGURE 7. (1972-1978 DATA)



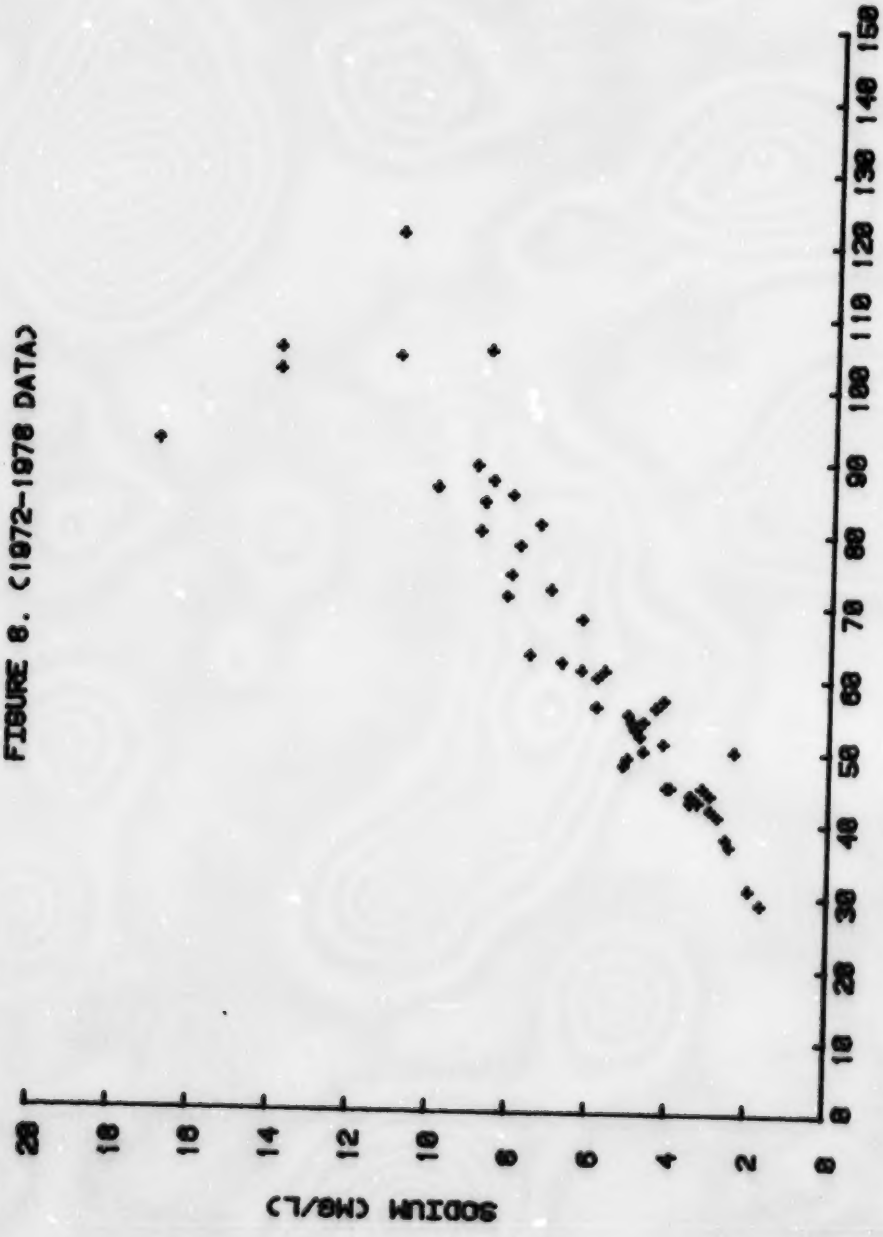


FIGURE 8. (1972-1978 DATA)

FIGURE 9. (1972-1978 DATA)

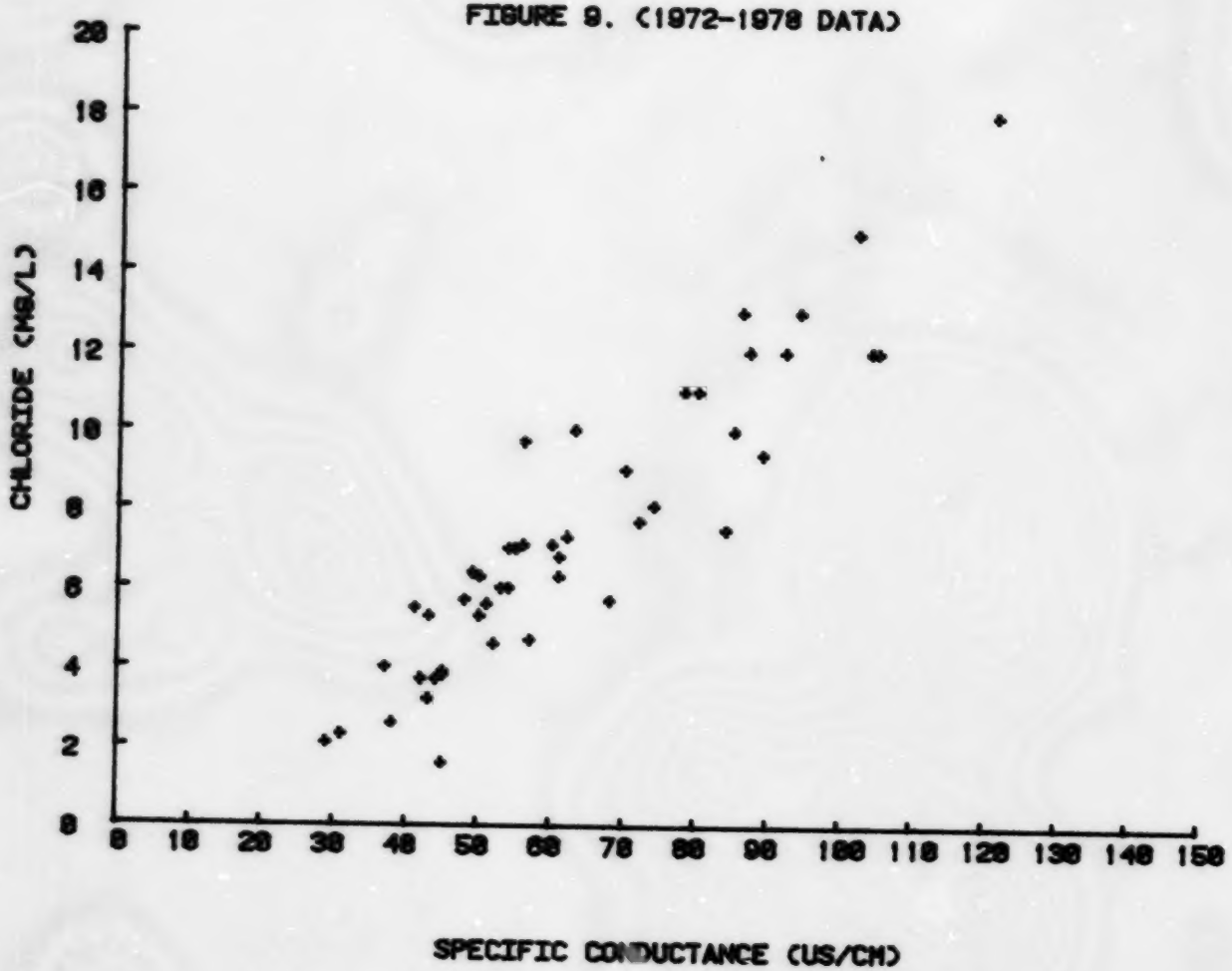
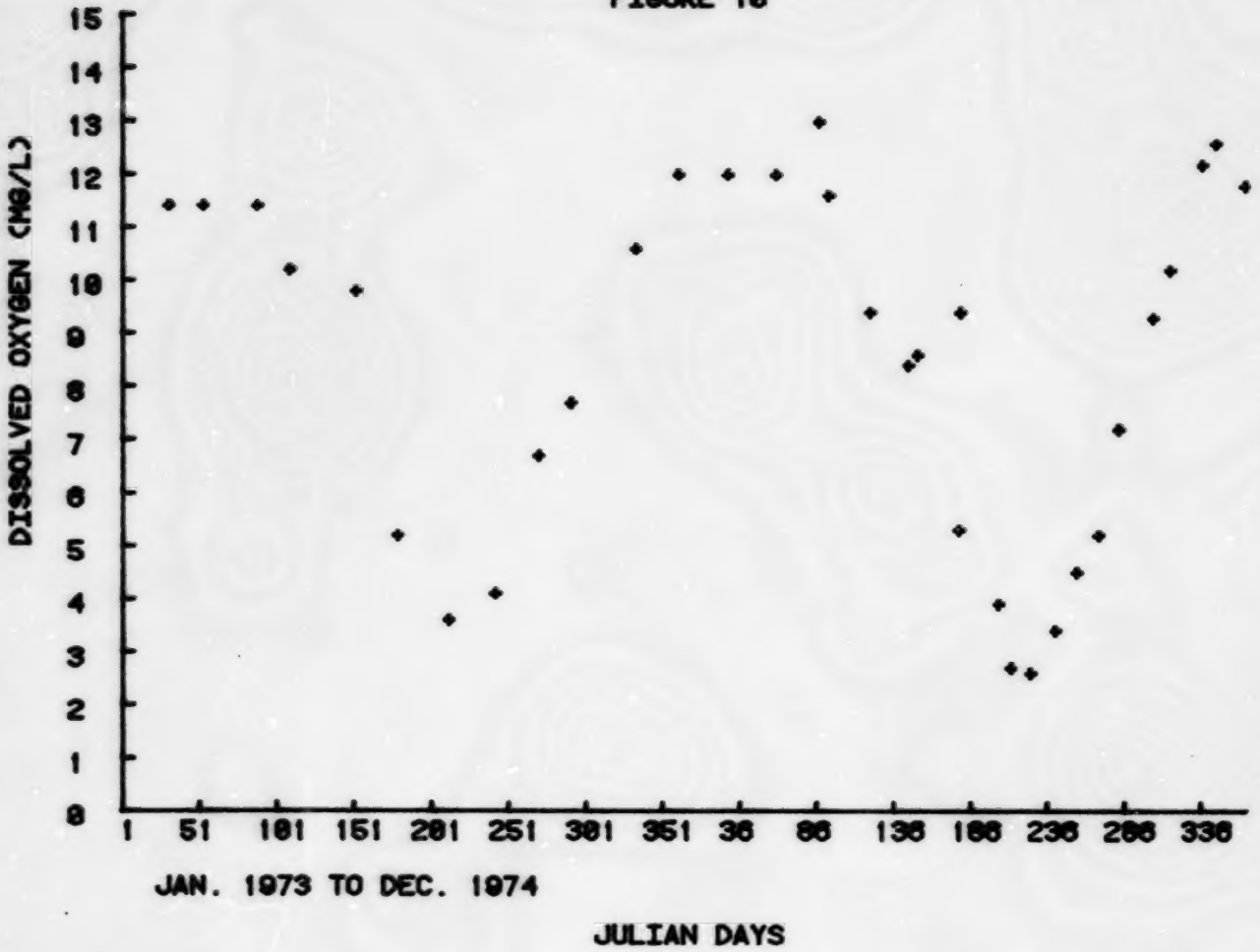


FIGURE 10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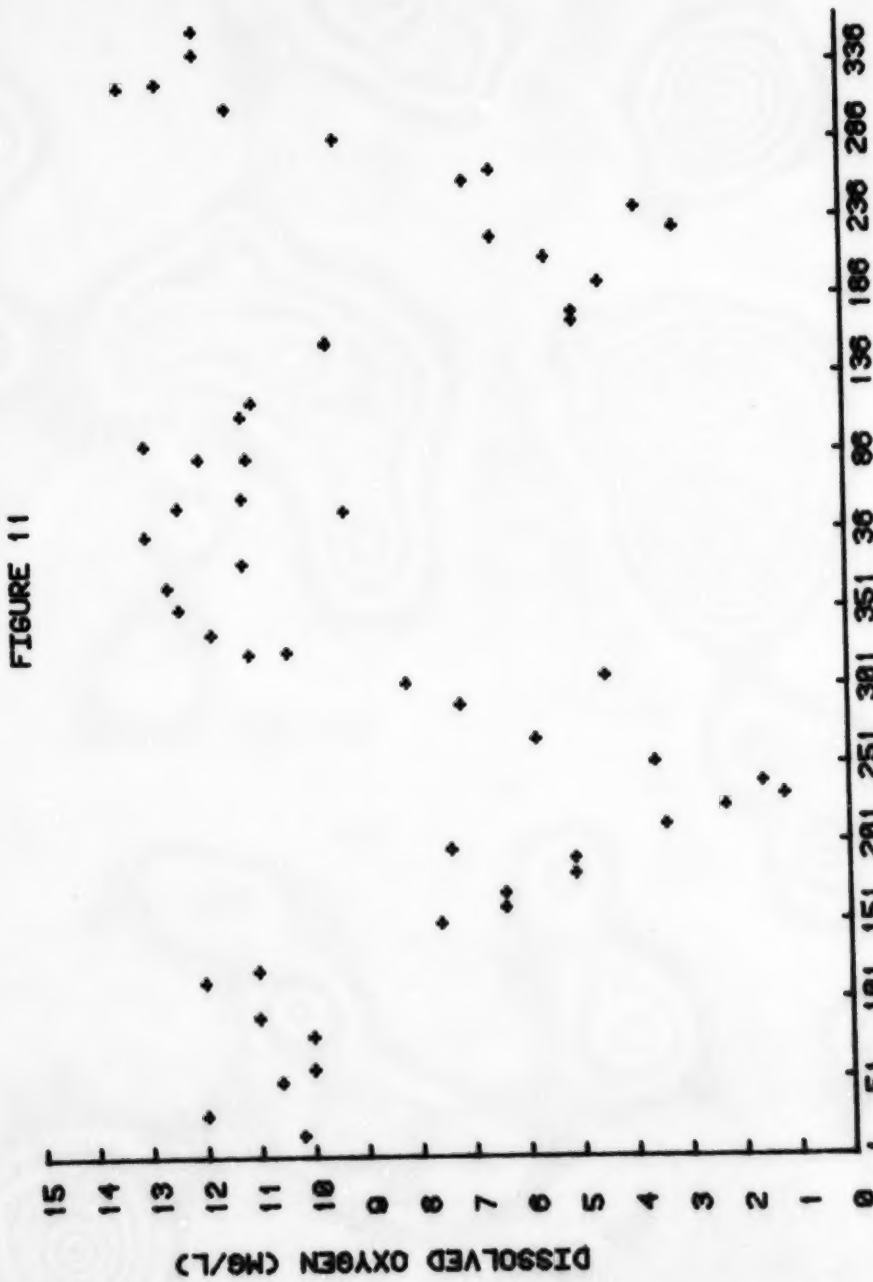
JAN. 1973 TO DEC. 1974
JULIAN DAYS


DISSOLVED OXYGEN (MG/L)
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JAN. 1975 TO DEC. 1976
JULIAN DAYS

FIGURE 11

FIGURE 12. (1978-1981 DATA)

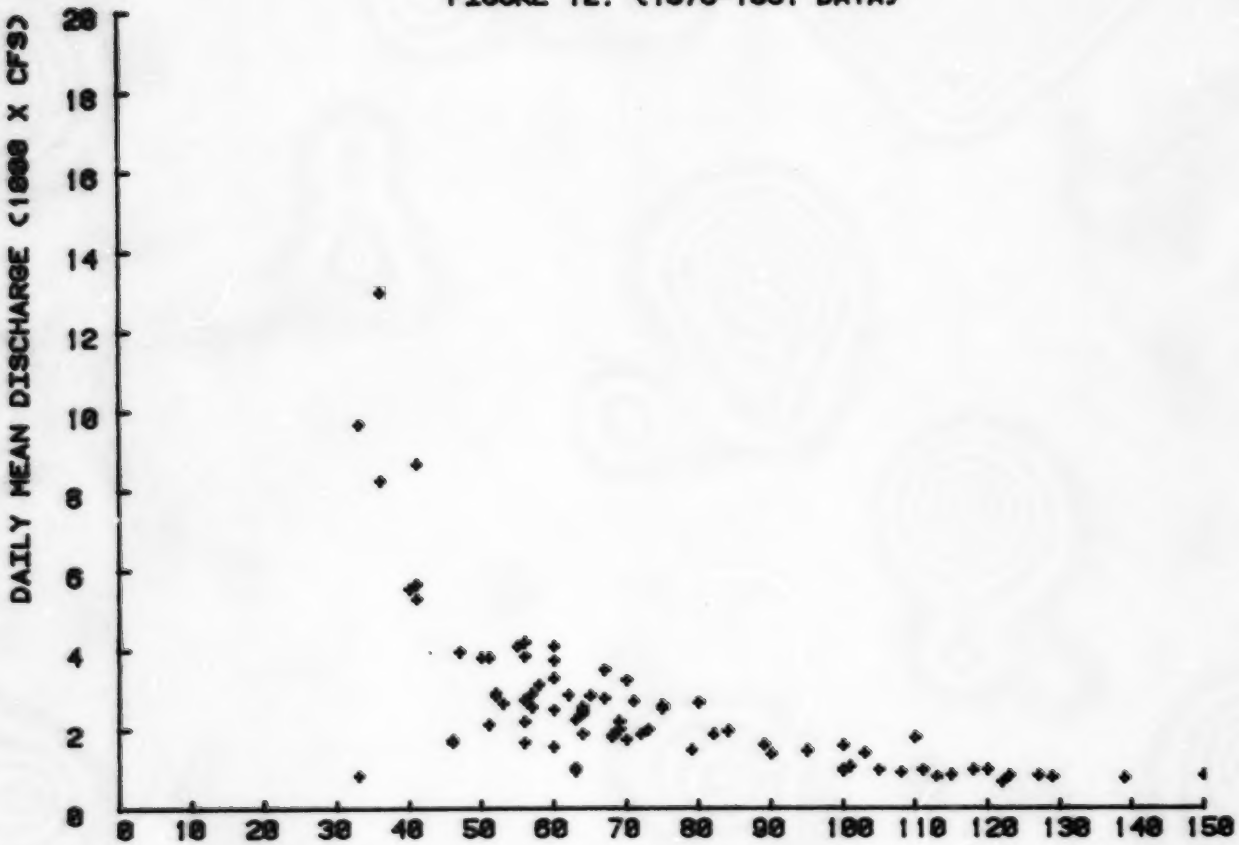


FIGURE 13. (1978-1981 DATA)

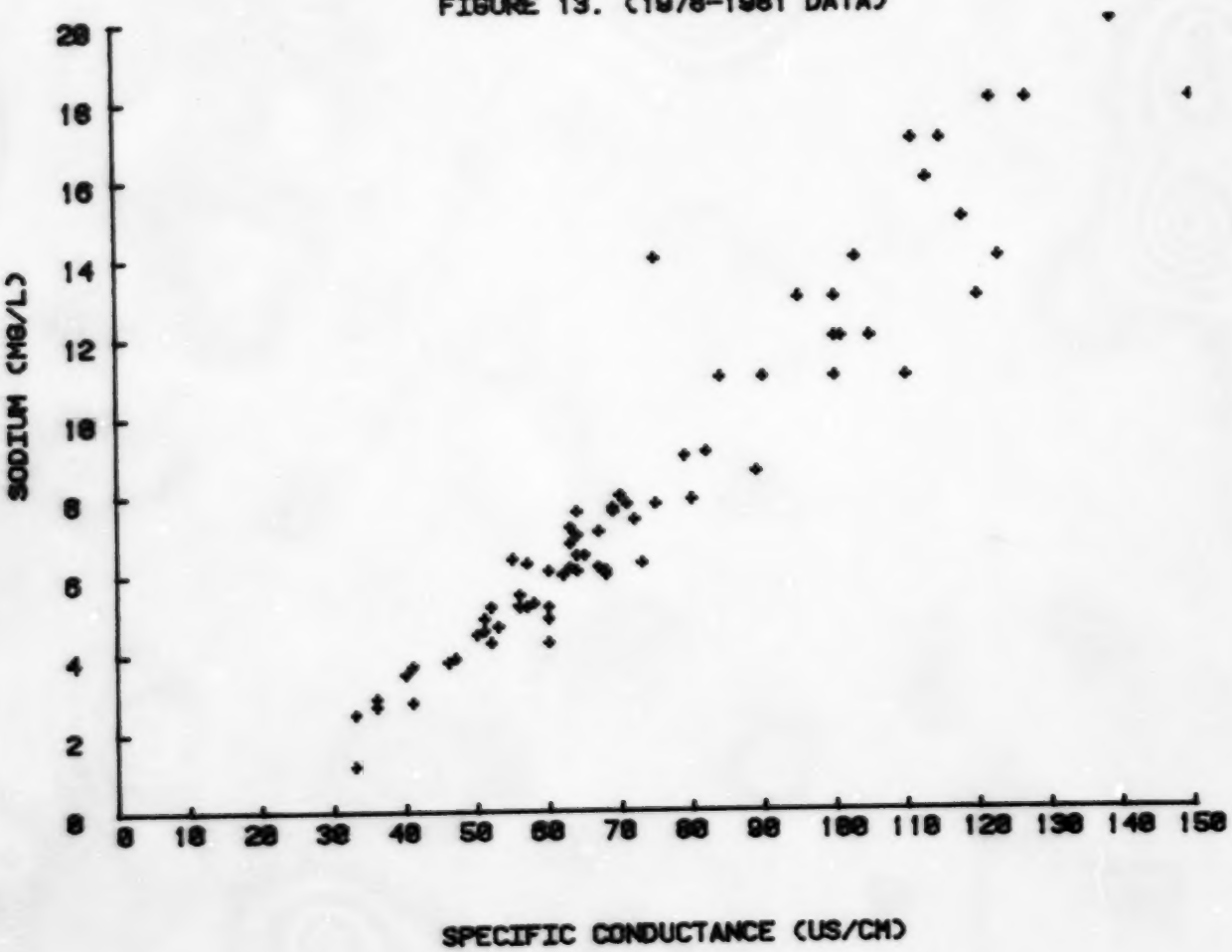


FIGURE 14. (1978-1981 DATA)

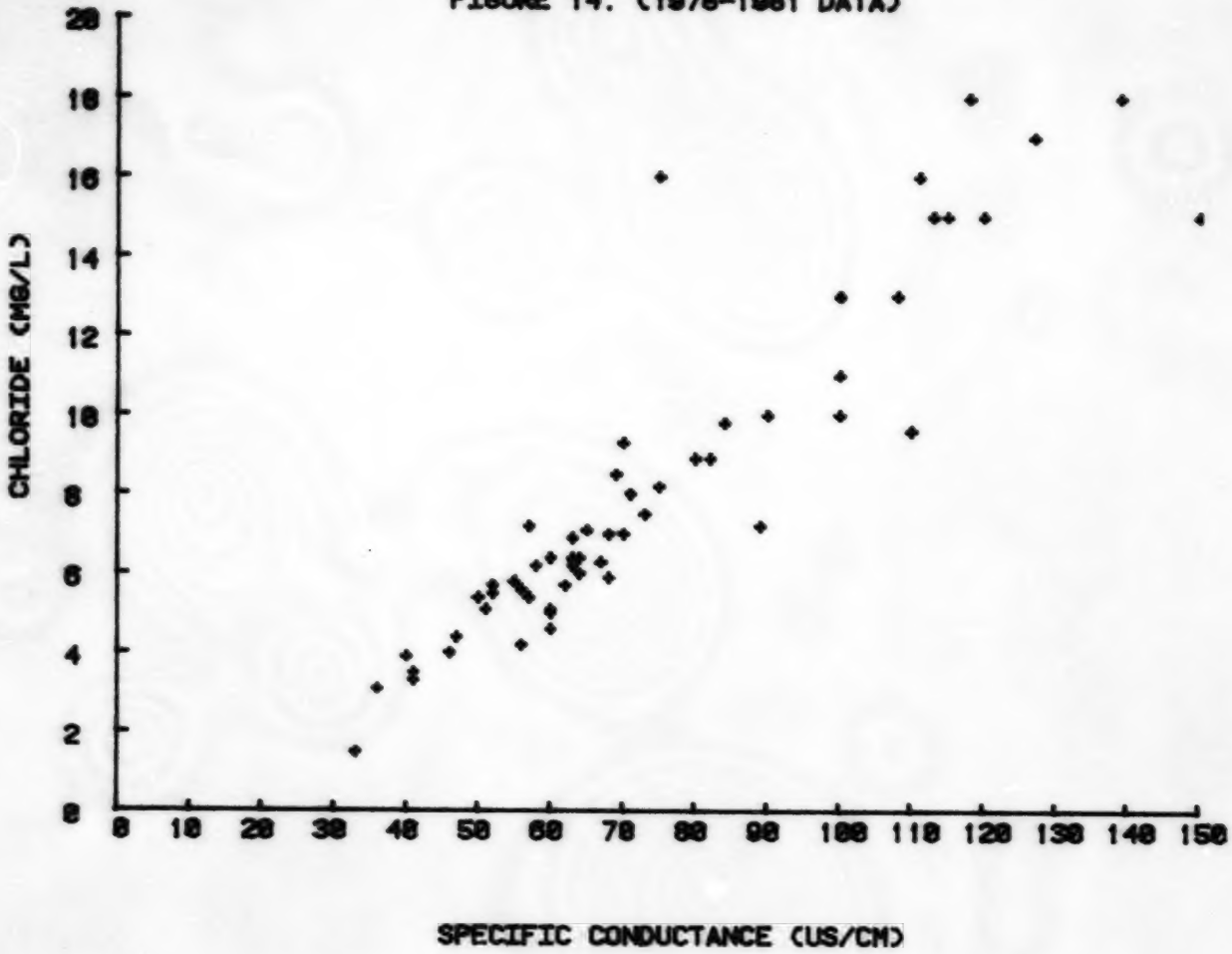


FIGURE 15. (1978-1981 DATA)

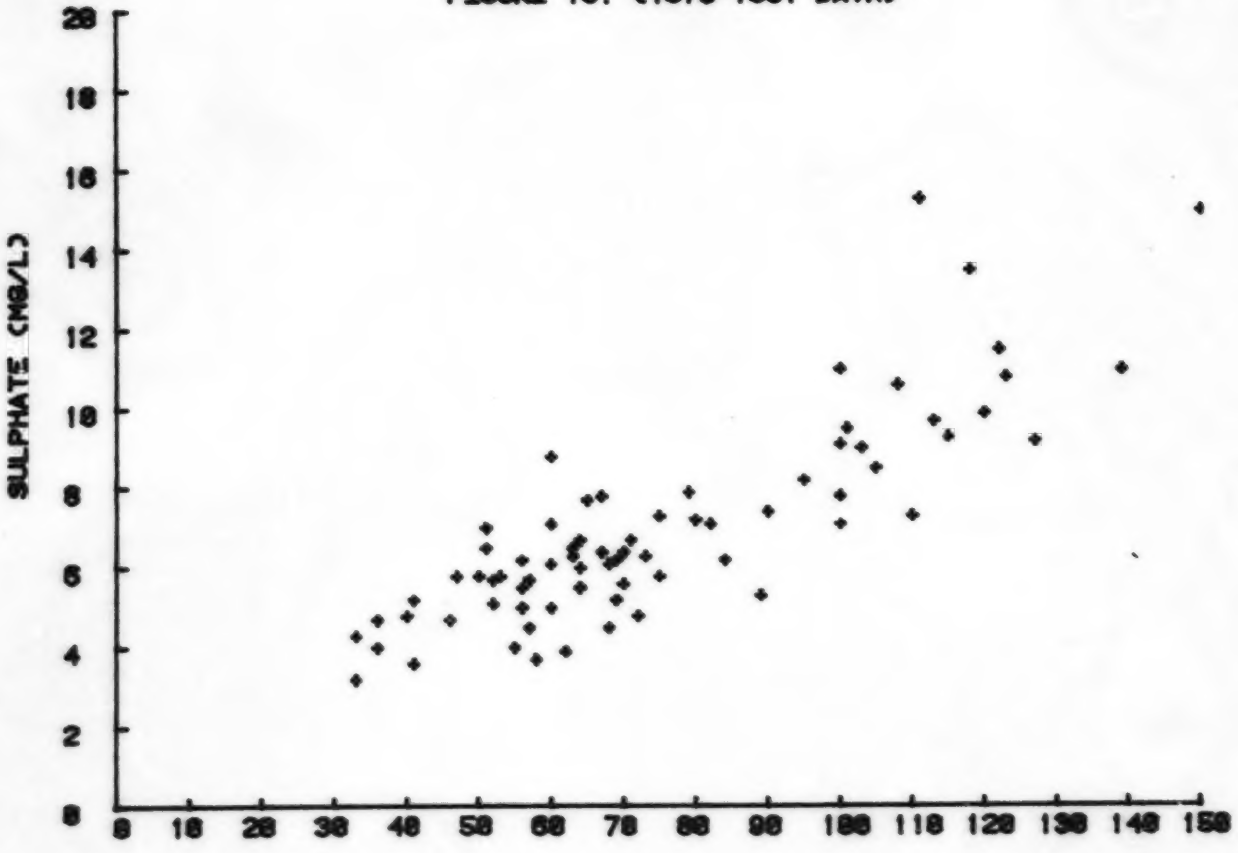
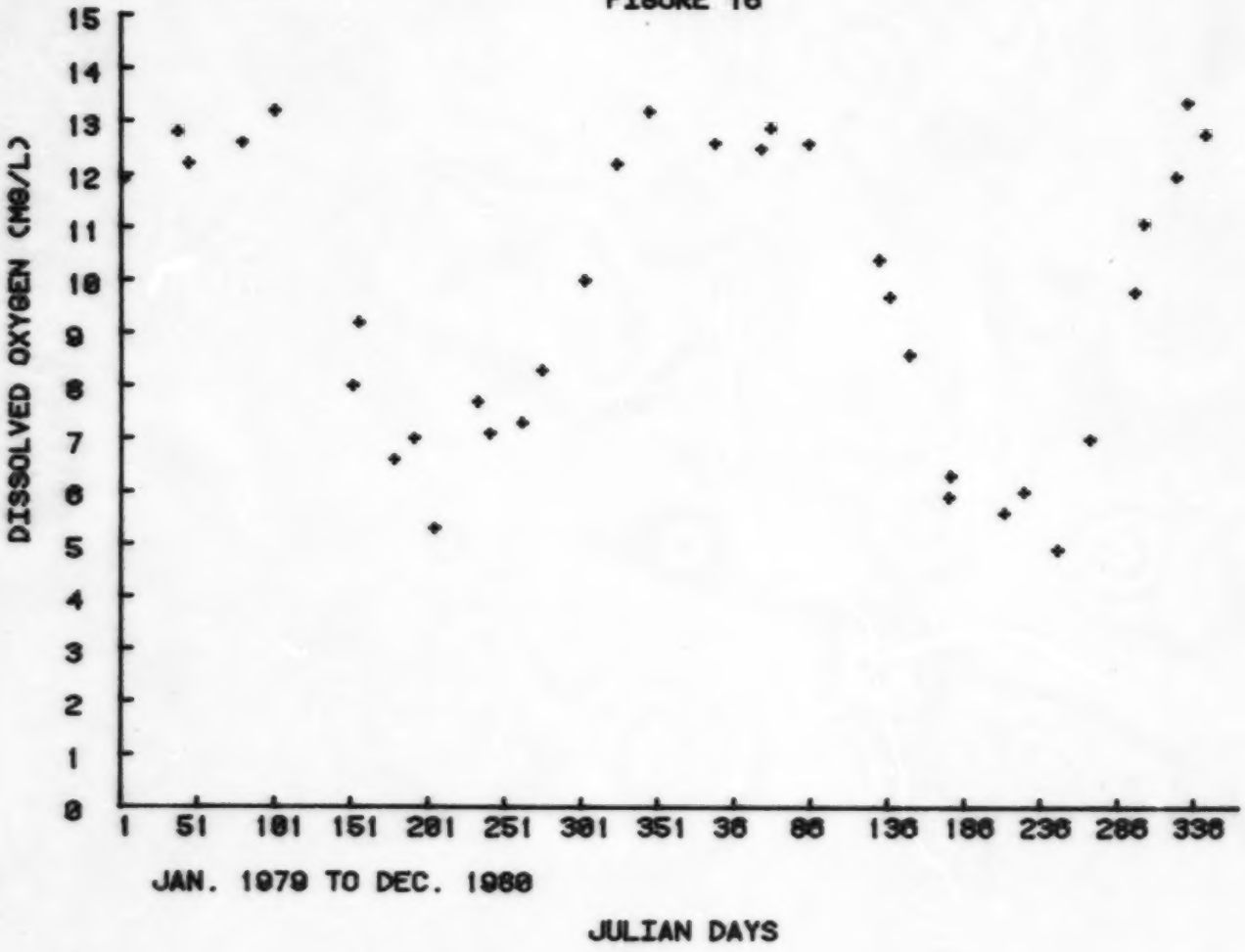


FIGURE 16


DISSOLVED OXYGEN (MG/L)
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JAN. 1979 TO DEC. 1980
JULIAN DAYS